SUPPORTING A MATHEMATICIANS' INSTRUCTIONAL CHANGE IN UNDERGRADUATE MATHEMATICS THROUGH FACULTY COLLABORATION

Nicholas Fortune
Western Kentucky University
nicholas.fortune@wku.edu

Karen Keene
North Carolina State University
kakeene@ncsu.edu

To reform instruction by moving towards student-centered approaches, research has shown that faculty benefit from support and collaboration (Henderson, Beach, & Finkelstein, 2011; Speer & Wagner, 2009). In this study, we examined the ways in which a mathematician's instruction unfolded during his participation in a faculty collaboration geared towards reforming instruction and aligning it with inquiry oriented instruction (IOI) (Kuster, Johnson, Andrews-Larson, & Keene, 2017). Results indicate the participant's mathematics background and research interests influenced how he used student thinking in his instruction. Further, there existed a tension between IOI and anticipating student thinking. Lastly, results highlight the importance of active participation in faculty collaboration to support instructional change.

Keywords: Post-Secondary Education, Teacher Education-Inservice/Professional Development

Over the last decade there have been numerous calls for reform in undergraduate mathematics education (e.g., President's Council of Advisors on Science and Technology [PCAST], 2012). These calls for reform draw on research that has shown the benefits of student-centered instruction (e.g., Freeman et al., 2014). To address these calls, change is needed in the instruction of undergraduate mathematics. For example, *A Common Vision* gave a general call that instruction should move away from traditional lecture as the sole instructional method in undergraduate mathematics (Mathematics Association of America [MAA], 2015).

Given these calls for instructional reform, faculty want to make changes to their instruction. However, research has shown that even when working with research-supported curricular materials, mathematics faculty are often unprepared to undertake the challenge of changing their instruction (Henderson et al., 2011; Wagner, Speer, & Rosa, 2007). Current research is providing mathematics faculty with support needed to change their instruction.

There are also calls for departments and faculty members to collaborate specifically on the pedagogy (MAA, 2011). One research-based method of support is faculty collaborations geared towards collectively improving instruction (e.g., Nadelson, Shadle, & Hettinger, 2013). In particular, researchers are studying how mathematics faulty come to use research-based instructional strategies in their classrooms in the context of faculty collaboration. This study explored the experiences of a mathematician who participated in one such faculty collaboration that addresses the numerous calls for reform in undergraduate mathematics education and instruction. The study addressed the following overarching research question: *1) In what ways does one mathematician's experiences in an online faculty collaboration on inquiry oriented differential equations relate to his instructional practice?* And the following sub research questions: *a) How does his instructional practice unfold over his first implementation of inquiry oriented differential equations and in what ways does it align with inquiry oriented instruction? b) How does his participation unfold in the online faculty collaboration?*

Literature Review

In this section, we briefly describe the instruction that the faculty collaboration sought to support. Following this we briefly discuss relevant research on instructional change.

Hodges, T.E., Roy, G. J., & Tyminski, A. M. (Eds.). (2018). *Proceedings of the 40th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*. Greenville, SC: University of South Carolina & Clemson University.

Inquiry Oriented Mathematics

The faculty collaboration focused on inquiry oriented mathematics and instruction. Rasmussen and Kwon (2007) defined inquiry oriented (IO) environments as teaching where students are inquiring into the mathematics, while the teachers are inquiring into the students' mathematical thinking. In this study, we focused on inquiry oriented differential equations (IODE) which has been shown effective for student understanding of differential equations (Kwon, Rasmussen, & Allen, 2005; Rasmussen, Kwon, Allen, Marrongelle, & Butch, 2006).

Inquiry oriented instruction. In inquiry oriented mathematics, it is clear that the role the teacher plays is important for advancing the mathematical agenda. Kuster et al. (2017) recently defined four focal components of inquiry oriented instruction (IOI): generating student ways of reasoning, building on student contributions, developing a shared understanding, and connecting to standard mathematical language and notation. The focal components of instruction are guiding principles of IOI. It is important to note that the four focal components very rarely occur independently; oftentimes, these components overlap and occur in the complexities of an IO classroom. Further, there are local practices of IOI. The local practices of IOI (see Table 1) are an elaboration on the four focal components of IOI. While the focal components are guiding principles of IOI (i.e., ways of composing and discussing IOI), the local practices are specific actions that instructors do in an IO classroom.

Table 1: Inquiry oriented instructional local practices (Kuster et al., 2017)

Local Practice	Description
1	Teachers facilitate student engagement in meaningful tasks and mathematical activity related to an important mathematical point.
2	Teachers elicit student reasoning and contributions.
3	Teachers actively inquire into student thinking.
4	Teachers are responsive to student contributions, using student contributions to inform the lesson.
5	Students are engaged in one another's thinking or reasoning.
6	Teachers guide and manage the development of the mathematical agenda.
7	Teachers introduce language and notation when appropriate and support formalizing of student ideas/contributions.

Overview of Instructional Change

Here we first describe barriers to instructional change and then what the research community knows about facilitating and sustaining instructional change.

Barriers to instructional change. One barrier to instructional change is faculty's knowledge for teaching with student-centered instructional strategies. Research has shown that some faculty lack the necessary skills to enact student-center instruction (Hayward, Kogan, & Laursen, 2015), sometimes because they lack specialized content knowledge relating to instruction and being prepared to respond to student questions productively (Wagner et al., 2007). Further, faculty have stated that student resistance, lack of student buy-in, and student attitudes of school are reasons why they do not use student-centered instruction (DeLong & Winter, 1998). The most often cited environmental reason by faculty to not use student-centered instruction is how much more time it takes than teacher-centered instruction (Henderson & Dancy, 2017). Likewise, faculty say they stray away from student-centered instruction because they have a certain amount

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of material that needs to be covered over the course of one semester (Hayward et al., 2015).

Facilitating and sustaining instructional change. Henderson et al. (2011) outlined four categories of instructional change strategies that are elaborated on in this section: disseminating curricula and pedagogy, developing reflective faculty, enacting policy, and developing a shared vision. Borrego and Henderson (2014) elaborated on these four categories of change by defining eight change strategies that fit within the framework. This study considered two of these change categories that we discuss here: scholarly teaching and faculty learning communities. Scholarly teaching is when "individual faculty reflect critically on their teaching in an effort to improve" and faculty learning communities are when a group of faculty come together and "support each other in improving teaching" (Borrego & Henderson, 2014, p. 227). These two strategies can work together to improve undergraduate mathematics instruction.

Methods

This study focused on one participant from an IODE online faculty collaboration (OFC). This qualitative instrumental case study (Stake, 1995) was bounded by the participant's participation in the OFC and his classroom teaching. This work comes from the TIMES project, which supported university mathematics faculty in shifting their practice towards an IO practice. TIMES offered three supports: the IO materials (in this case IODE), a summer workshop, and the weekly OFC. Here we first highlight pertinent details on the OFC.

Online Faculty Collaborations

The IODE OFC met weekly during the semester they are teaching IODE, virtually via Google Hangouts to conduct lesson studies that were modified Japanese lesson studies (Demir, Czerniak, & Hart, 2013) led by a facilitator. The main goals of the OFC were to: 1) aid teachers in making sense of the instructional IODE materials, 2) thinking through the sequences of tasks, how students might approach the tasks, how to structure instruction around the tasks to support student learning, and 3) assist teachers in developing and enhancing their instructional practice.

Participant

The focus of this study is one participant from the IODE OFC, Dr. DM. The OFC consisted of the facilitator (Dr. KK), two graduate research assistants (GRA1 and GRA2), five faculty teaching the materials for the first time (Drs. DM, AB, PR, CD, ST). The sampling of Dr. DM was purposeful in nature (Yin, 2013) and there were several reasons for that choice. First, he was and is passionate about his participation in TIMES and to this day continues with IOI in his IODE classroom. Second, he became a facilitator for the project in future semesters following his participant experience. Furthermore, Dr. DM filmed every class of the semester, which was more than was expected of the other TIMES participants, affording a plethora of possible data sources and a semester-long look at instruction.

Data Collection and Analysis

Classroom data. Video data from Dr. DM's classroom were collected. Classroom video was chosen to match the units covered in the OFC lesson studies. The OFC discussed Unit 6 and Unit 9. In addition to those units, Unit 1-2 as an introductory unit and Unit 12 were analyzed. All units lasted a different amount of time. The IOI framework discussed above (Kuster et al., 2017) was designed to capture IOI in action. Consequently, we used the framework as an a priori analytical framework for coding Dr. DM's classroom instructional practice to answer research question 1a. In particular, we used the local practices (LP) of IOI. The IOI framework also contained "evidences," not shown above, of each LP; these evidences served as codes that were collapsed to each LP. LP1 was not coded for unique observable instances in the data. After the

first round of coding, we went back again and revisited analysis logs and made adjustments to the coding as necessary. In this step, we looked for emergent themes from the data.

OFC data. Each OFC was screencast recorded. All weeks of the OFC were analyzed except week 6 because the data was corrupted and week 8 because Dr. DM was unable to attend that week (in total 9 OFCs were analyzed). Weeks 1 and 2 were introductory weeks. Lesson study 1 took place over weeks 3-5 and lesson study 2 took place over weeks 6-10. Lastly, a debrief OFC occurred during week 11. All videos were transcribed. To analyze Dr. DM's participation in the OFC we coded the transcripts with specific a priori codes and frameworks: the role of the speaker (production design from Krummheuer, 2007), the role of the listener (reception design from Krummheuer, 2011), and conversation categories (Keene, Fortune, & Hall, under review). These frameworks were adapted to fit the context of this study and are discussed in the results. In a broad sense, we considered Dr. DM's active versus passive participation.

Interview data. The interview data served as a third data source to relate Dr. DM's experiences in the faculty collaboration to his instructional practice. Furthermore, this data offered Dr. DM's personal perspective on being part of a faculty collaboration. Entrance and exit semi-structured interviews were conducted. All interviews were audio recorded and transcribed. Transcripts of both interviews were open coded (Yin, 2013).

Results

Instructional Practice

Central to IOI is the facilitation of mathematics where students are actively inquiring into the mathematics while the teacher is actively inquiring into the students' mathematical thinking (Rasmussen & Kwon, 2007). Dr. DM's instruction focused predominantly on LP2, eliciting student ways of reasoning and contributions (see Table 2). Dr. DM less often actively inquired into why his students were making such contributions (LP3), less often used those contributions to push the agenda forward (LP4), and less often had students engage in one another's thinking (LP5; although this happened frequently in Unit 1-2). Note that frequencies were scaled and rounded to represent the same amount of class time; each unit lasted a different number of days.

Table 2: Frequencies of Dr. DM's Local Practices of Inquiry Oriented Instruction

Practice	Unit 1-2	Unit 6	Unit 9	Unit 12
2	58	52	66	26
3	17	24	16	4
4	17	16	15	8
5	42	26	14	2
6	14	16	6	4
7	3	14	8	2

Table 2 is very telling of Dr. DM's instruction. He was very interested in generating student contributions. While some of the questions asked were ones from the IODE tasks themselves, he often would ask his own questions in his own way as a means to address something that he wanted to focus on or have his students think about. While students had opportunities to engage in others' contributions as they were written on the board, they less often had opportunities to engage in others' thinking, as Dr. DM did not tend to follow up with questions to have students elaborate on their thinking. Essentially, after students made contributions, Dr. DM would more often move on. We cannot know for sure if Dr. DM was so in tune with the students in his class and the mathematics itself, that he did actually know why his students were thinking along

certain lines. However, LP3 and LP4 are about making explicit to the rest of the class such thinking and thus Dr. DM's LP frequencies were reflective of the fact that he didn't often make public his inquiring into student thinking.

Dr. DM's instruction did not necessarily change from the beginning of the semester to the end of the semester. As discussed across the totality of Dr. DM's instruction his most frequent LP was LP2, eliciting student ways of reasoning and contributions. However, when comparing the four units of analyzed instruction there were contrasts between the unit instructional portraits. Namely, the way Dr. DM's instruction unfolded was tied to 1) how and when he used student thinking in his class, 2) the mathematical task itself, and 3) his mathematical beliefs, rooted in his mathematical research arena.

First, in Unit 1-2, Dr. DM frequently (more often than any other unit when comparing across scaled time) engaged students in one another's thinking. In particular, this unit was the unit where his students' thinking was most at the forefront of the class and he oftentimes used that thinking to advance the mathematical agenda. When student thinking was made prevalent to the rest of the class, Dr. DM's instructional portrait reflected that.

Second, it was observed that Dr. DM's instruction was influenced by the mathematical task. Specifically, if a unit was a more scaffolded unit with limited options for student exploration (e.g., Unit 12), the questions that Dr. DM would ask were limited in scope and thus he used less IOI LPs in those units. In this particular case, Unit 12 was a very algebraic unit where students, being led by the teacher, develop an understanding of how to find the eigenvalues of a system of differential equation and use that information to find the associated eigenvectors and in turn the solution to the system of differential equations. Consequently, the questions Dr. DM could ask and the probing he could do was significantly impacted and all IOI LPs occurred less often.

Third, when the mathematics of the unit was associated with Dr. DM's mathematical research interests he would focus on getting students to get to "the way [he] view[s] the mathematics" rather than having his students' work or ideas at the center of the development of the mathematical agenda. Unit 9 dealt with the development of the phase plane which was a crucial tool in Dr. DM's research. The instructional portrait of that unit had the highest amount of eliciting student ways of reasoning and contributions (LP2) and in comparison, a very low frequency of LP3-5 (the other practices associated with student thinking). Many of the questions that Dr. DM asked were of his own accord and not generated from the whole class discussion. Because he knew the mathematics so intimately, he was most interested in getting students to see the mathematics the way he does, rather than letting the mathematics emerge from the students.

Participation in OFC

Recall the goal of the OFC was to support cohorts of mathematicians as they came to learn about IOI and IODE. Table 3 highlights the participation frequencies based on role and conversation. For the purposes of space, we only discuss active and passive participation here rather than all the more specific roles adapted from Krummheuer (2007, 2011). Additionally, we adapted frameworks from our previous work (Keene et al., under review) but here only include four broad conversation categories rather than each individual conversation topic.

Rather than growth throughout the semester, Dr. DM immediately jumped into the active role in the OFC and that active role was consistent throughout the semester. Similar to his classroom instruction there was not a change but rather how his role looked depended on the content of each OFC. For example, if the week focused on doing mathematics, he rarely authored topics because he simply was partaking in the conversation, however, he was very active in those weeks as he has a real passion for mathematics. Additionally, when the OFC focused on sharing

of his videos, he authored frequently those weeks and the conversation focused on pedagogy as he sought advice on, for example, how to speed up his class because he was running out of time at the end. Table 3 highlights Dr. DM's most active role related to pedagogical issues.

Table 3: Frequencies of Speaker / Listener Codes by Participation / Conversation Category

Conversation Category	Speaker		Listener	
	Active	Passive	Active	Passive
Pedagogical Issues	137	16	82	55
Mathematical Issues	70	6	72	40
Student Issues	63	2	20	23
OFC Issues	97	24	91	156

Discussion

In this section, we provide an answer to the overall research question.

Mathematics Background

Dr. DM's mathematics background played a role in how his instruction panned out throughout the semester and how he participated in the OFC. In both cases his mathematical content knowledge (rooted in his background and research interests) was placed on top of his interest in enhancing his pedagogical practice. By that we mean, in his teaching his view of mathematics sometimes was the view of mathematics that he was guiding his students towards. Likewise, in his participation in the OFC, his mathematical understanding was one of the driving factors for his interest in enhancing his pedagogical practice. Namely, he sought support on how he can get his students to that same level of awe and understanding.

This conclusion supports previous work from Speer, Wagner, and colleagues (Speer & Wagner, 2009; Wagner et al., 2007). However, there are important distinctions that shed light on this topic and provides discussion for faculty collaborations going forward. Most importantly, that is the subtle notions of what a mathematician's mathematical content knowledge is. In their work, Speer and Wagner noted that their participant had a strong understanding of the mathematical content but that did not help in terms of his analytic scaffolding (i.e., meaning facilitation of discussion). Similarly, Dr. DM also had a strong understanding of the mathematical content across all units. However, the difference lies in the fact that in some units he was able to provide analytic scaffolding, namely, he was able to use his students' ideas in the class (LP3: actively inquiring into student thinking, LP4: being responsive to student contributions, LP5: engaging students' in one another's thinking, LP6: guide the mathematical agenda). Yet, he was more likely to do that when the mathematical content wasn't his specific research interest. Consequently, we concur with Speer and Wagner and posit that one's mathematics background is not sufficient to successfully use student thinking in one's class, however, the level to which one understands that content makes a difference in their instruction.

Tension Between Agenda and Inquiry

This first relationship translates into a second one, as there is a tension between what a mathematician wants to do in his/her class and IOI. In the case of Dr. DM, his focus, for some of the content from the course, was to get his students to his view of the mathematics. This ultimately leads to a tension between one's teaching agenda and inquiry. If in inquiry, student thoughts are central to the development of the mathematical agenda (Kuster et al., 2017), then imposing one's own view of mathematics does not align with an inquiry perspective. The reason this causes a tension is because being passionate about your research inherently is not a bad thing, nor trying to get your students to see the beauty of mathematics. However, in so doing,

one privileges their understanding over that of their students.

Anticipating Student Thinking

A third relationship that relates Dr. DM's instruction to his participation in the OFC considers how one anticipates student thinking and how student thinking is used in instruction. We know from extant literature that mathematicians often struggle to implement novel teaching (if it is new to them) and in particular struggle with how to respond to and deal with student contributions in a productive and successful way (Wagner et al., 2007). However, this was not an issue for Dr. DM as he was in an OFC supporting his instruction. He never noted that he was unsure what his students were going to do. Yet, he seldom actively inquired into his students thinking. This indicates he either knew what his students were thinking or simply did not probe into their thinking; we cannot know which one.

We also know from extant literature on the possible successes of anticipating student thinking in professional development settings (e.g., Demir et al., 2013). In the OFC, participants spent 1-2 weeks for each lesson study doing the mathematics of the units of focus and then anticipating how their students may approach the tasks. This model was based off of the Japanese lesson study (Demir et al., 2013). Ultimately, we conjecture there is a tension between anticipating student thinking and inquiry oriented instruction. By that we mean that because a critical component of inquiry oriented instruction is inquiring into student thinking and engaging with unexpected contributions, if student contributions are overwhelmingly "anticipated," mathematics faculty may struggle to engage with those unexpected contributions if they spend a large amount of time anticipating what their students will do.

Active Participation in Faculty Collaborations

The fourth relationship centers around active participation in the OFC positively impacting instruction. As discussed, Dr. DM was an active participant in the OFC. Additionally, his goals were clear in that he was there to enhance his pedagogical practice. Dr. DM's passion for IODE and IOI bled into both his instruction and participation in the OFC. This OFC was an example of what Borrego and Henderson (2014) defined as a faculty learning community. "STEM undergraduate instruction will be changed by groups of instructors who support and sustain each other's interest, learning, and reflection on their teaching" (Borrego & Henderson, 2014, p. 233). Dr. DM was supported by and supported his fellow colleagues in learning about and reflecting on inquiry oriented instruction. This indicates that for successful instructional change, faculty learning communities or faculty collaborations needs to be designed with ensuring active participation from all involved.

Conclusion

This area of research is ripe for future research directions. The instruction of undergraduate mathematics courses is a hot button item in undergraduate mathematics education research today. More importantly, the research community still needs to know more about how we can support endeavors to reform instruction, how can they be scaled up, and how do we measure success? In this qualitative instrumental case study, while not generalizable, we can conclude that the OFC supported Dr. DM's desire to reform his instruction. This work has highlighted how those faculty collaborations can be improved moving forward and most importantly highlights that instructional change is possible if the time and effort are put into it.

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